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Plastics combined with metals in the production of desk objects

Sharon Church

PLASTICS COMBINED WITH METALS
IN THE PRODUCTION OF
DESK OBJECTS

BY

SHARON CHURCH

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I dedicate this thesis to my fellow students. Any information imparted to them through this work is small compensation for all they have taught me.

PREFACE

Working with plastics and metals in the production of several desk objects has involved gathering material on plastics from various sources and applying this information to the individual projects made as part of this thesis. The written portion will describe what plastics are and how they were combined with non-ferrous metals in accordance with my designs. I would like to thank Kener Bond, Hans Christensen, Jim Herman and Robert Peterson for their great help on this project.

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INTRODUCTION

Plastics materials constitute some of the most familiar items in anyone's everyday life. They have become so common that it is perhaps somewhat of a paradox for a silversmith or goldsmith to incorporate this material into his work. However, the giant growth of the plastics industry, especially since World War II, has resulted in products with very special qualities which, when properly used, may best fulfill the craftsman's conception.

In today's industry, new plastic products are constantly appearing; improvements are an expected phenomenon. Because of the many different types of materials available, one can pick from a number of plastics for specific properties, such as color, transparency, weight, flexibility, etc. The many different qualities that each plastic possesses offer a diverse range of materials to someone who finds a plastic may best suit his needs. Though it will not be the purpose of this thesis to describe the many different types available, it is hoped that a general explanation of what plastics are and how I chose to incorporate them into my work will encourage others interested in exploring some aspects of this material in their own work.

CHAPTER I

GENERAL INFORMATION CONCERNING PLASTICS

The Chemistry of Plastics

Defining what characteristics are peculiar to plastics materials is not an easy task, as there are many materials which are 'plastic'. (The word itself implies ease of deformation.) Arthur Dunham describes the material plastic as a synthetic or semi-synthetic material which can be molded under heat and/or pressure and retain that shape after the heat and/or pressure is removed.[1] Couzens and Yarsley add that plastics can be deformed under mechanical stress (such as heat and pressure) without losing cohesion.[2] The American Society for Testing Materials and the Society of the Plastics Industry refers to this as being shaped by flow.[3] Curiously, however, a plastics rarely becomes liquid, but rather flows as a solid form.

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[1]Arthur Dunham, Working with Plastics, (U. S., McGraw - Hill, 1948). p. 1.

[2]E. G. Couzens and V. E. Yarsley, Plastics in the Modern World, (Baltimore, Md., Penquin Books, Ltd., 1968). p. 27.

[3]Lionel K. Arnold, Introduction to Plastics, (Ames, Iowa, The Iowa State University Press, 1968). p. 3.

What really differentiates plastics from other materials is the enormous length of its molecular chains and their entanglement with one another. All plastics are a mass of huge molecules and thus belong to the chemical family of high polymers. A polymer is a large molecule made of repeating small, simple chemical units called monomers. The process through which these units are linked together is called polymerization. Sometimes two different monomers will link to form a long chain, the result being a copolymer.

Peculiar to plastics also is that they are based on carbon and are therefore organic. Thus one finds "the fundamental structure of plastics as long chain molecules built up essentially from carbon, with other atoms occasionally interposed."[4]

All plastics can be divided into two groups, thermoplastics and thermosetting plastics. Thermoplastics can be softened and resoftened indefinitely through the application of heat and/or pressure. Thermosets are chemically changed when they are initially subjected to heat and/or pressure, after which they can no longer change shape. The structural reason for this is that the molecular

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[4]E. G. Couzens and V. E. Yarsley, Plastics in the Modern World. p. 38.

chains of thermoplastics are linearly linked and therefore are free from one another and capable of flow. The molecular chains of thermosetting plastics are cross-linked and are therefore locked together, and cannot flow.

Polymerization may occur through three different methods. In addition polymerization the double bond between two atoms is induced to open up and link to other atoms in a long chain. The change is brought about through heat and/or pressure, or the presence of a catalyst, or initiator. The result is a thermoplastic.

Condensation polymerization differs in that some small molecule (usually water) is split out during the reaction, and it is not essential that the monomer have a double bond. Dissimilar molecules are dovetailed into one another by means of a chemical change due to the presence of heat and/or pressure, or that of a catalyst. The result may be either a thermoplastic or a thermoset.

The third method, rearrangement polymerization, is an intermediate between, or rather combination of, addition and condensation polymerization. Through close control of polymerization, plastics can be tailor made to have certain qualities.

The character of a plastics is determined by chain flexibility, interchain attraction and regularity of the polymer.[5] Each plastic will have its own limits according to its degree of:

1. Solubility. "A chemical will be solvent for another material if the two materials are compatible."[6] The addition of certain chemicals to a polymer will gradually "push" chains apart until they ultimately separate.

2. Chemical Resistance. In order for a plastic to resist a chemical, each ingredient must be unaffected by that chemical.

3. Tensile Strength. The long molecular chains are coiled up and will stretch, then return to the original position. When the pressure exceeds the bond of the molecular chain, the material can stretch until it breaks. If the chains are tightly coiled, the plastic is brittle. Generally, the longer the chains, the tougher the material.

4. Resistance to Irradiation. Thermal, photochemical and high energy radiation may cause cross-linking and modification of chain structure.

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[5] J. A. Brydson, Plastics Materials, (Princeton, New Jersey, D. Van Nostrand Co., Inc., 1966). p. 45.

[6] Ibid. p. 64.

5. Aging and Weathering. A polymer's properties may alter through exposure to chemicals, heat and ultra-violet light.

6. Diffusion and Permeability. Small molecules may diffuse into, out of, and through plastics.

7. Temperature. Most plastics decompose at 200° centigrade, and none can withstand temperatures above 400° centigrade.

8. Yield Point. The point at which a plastics material begins to flow is termed "yield point".

Manipulation of these characteristics can be effected through close control of polymerization and careful addition of other ingredients to the polymer.

A resin is the principal material in the plastic product. To this high polymer fillers, colorants and plasticizers may be added. A filler is usually a solid, such as wood flour, which adds certain properties, such as opacity and strength. An extender is merely a filler used solely to cheapen the cost of the plastic. Plasticizers are either liquids or solids, usually organic, added to improve qualities such as flexibility and tensile strength, and to lower the yield point. Originally used to make the initial resin more plastic, they must have low volatility and now have such far reaching effects as to lower the water resistance of a plastics material. The result of this mixture of resin and other materials is a molding powder.

In order to polymerize, the monomer must be activated by the addition of energy. The application of heat and/or pressure may be done mechanically or can come about as the result of a chemical reaction. In any case, however, an initiator is required, which may be called a catalyst, accelerator or promoter. This catalyst is used to encourage the linking up of monomers. Inhibitors (sometimes referred to as stabilizers or retarders) will stop chain growth and thus the length of the chain can be controlled.

Through such modification, technology has developed various tailor made plastics. For instance, DuPont makes some fifty-odd nylons, each with special properties. Alteration of a plastic may result from the addition or substitution of chemicals in the polymer, the degree of polymerization (through the addition of inhibitors), the addition of plasticizers, fillers and extenders, and the controlled effects of irradiation. Ultraviolet rays may activate certain polymerization reactions; gamma rays may cross-link some thermoplastics, rendering them a thermosetting material!

The Manufacture and Mechanical Manipulation of Plastics

In the manufacture of plastics, the simplest method of polymerization is to allow the monomer to stand at the proper temperature with the catalyst until polymerization is complete. This is fine for a small mass, but problems arise when dealing with large quantities of material, and more complex methods have been devised to give a high quality product.

Both thermoplastics and thermosets may be cast by pouring the pre-mixed monomer and catalyst into a mold and letting the mixture harden either at room temperature or in ovens and autoclaves. This same process is used for embedment (the enclosing of materials in a block of plastic) and for potting (covering of parts). The casting mold may be of rubber, plaster, metal, or even gelatin.[7] Various shapes, such as rods, tubes and sheet, are cast, usually when other methods prove too costly.

Compression molding is used for thermoplastics and thermosets, (where the final polymerization takes place in the mold). The molding powder is placed in a hot mold and pressure applied, forcing

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[7] Harry B. Hollander, <u>Plastics for Artists and Craftsmen</u>, (London, Pitman Publishing, and New York, Watson-Guptill Publications, 1972), p. 47.

the powder to become fluid and flow all over the die. The mold is cooled and the piece released. Because about 800 pounds per square inch pressure is required, this application is more practical for industry than for most individuals.

Injection molding is used only for thermoplastics. The plastics powder is placed in a hopper from which an accurate portion is forced into a heating chamber and from there into the mold cavity. Because the die does not have to be heated, this results in fast production.

A similar method, jet molding, is used for thermosets. Adjustments are made so that once heated, the material is not allowed to cool until it has been molded and can cure in place.

Extrusion molding was also developed for thermoplastics. After the powder is heated, the process continues by "forcing a plastics material through a die to continuously produce such products as rods, tubes, films, bars, filaments and a variety of other elongated shapes with uniform cross sections."[8]

In addition to these processes, other methods have been devised to produce a variety of shapes. Blow molding entails softening a thermoplastic sheet and blowing it into a mold. Any marks on the mold

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[8] Lionel K. Arnold, Introduction to Plastics, p. 47.

will be left on the plastics. Similar to this is thermoforming. The softened thermoplastics (heated for at least 15 - 20 minutes in a 300° - 350° F. oven) is reshaped and cooled as that shape is mechanically maintained. When cooled it is permanently altered. To vacuum form a thermoplastics, a vacuum between a hot thermoplastic sheet and a mold causes air pressure to force the sheet against the mold; the shape is maintained until the material is cool.

In each of these processes the presence of "memory" in most thermoplastics must be taken into account. Deformation in a hot sheet can be frozen when the new shape is maintained through a reduction in temperature. However, that deformation is reversible if the sheet is raised to a temperature above that used in the shaping process. In addition, if the new shape is not maintained during cooling, the plastics will have a tendency to return to its original form.

Another method of shaping plastics is termed "hand lay-up". A reinforcing material (usually glass fibre mat) is placed on the surface of a mold which has been coated with a parting agent. The mat is then impregnated with resin and allowed to set up at atmospheric pressure, in an autoclave, or with bag pressure. Plastics may also be sprayed, brushed, or rolled on a prepared surface.

The metal plating of plastics has found great use commercially and is available to anyone in possession of a rectifier and the proper baths. Industrially, vacuum metallizing is commonly employed. The clean plastic is coated with an organic base coating of conductive paint or lacquer, then plated. A.B.S. (acrylonitrile-butadiene-styrene) is electroplated by first etching the plastic to roughen the surface. Then the entire surface is sensitized with tin salts (or activated) in a noble-metal salt solution, followed by plating with copper or nickel in an electroless plating bath, then plated with whatever metal desired.

Machining and Fabricating Plastics

Most metal machining tools can be adapted to or directly used for plastic drilling, sawing and polishing. For each plastic a guide such as The Modern Plastics Encyclopedia should be consulted for specific speeds, types of saw blades, etc. The following is general information concerning machining.

In drilling, it is best to regrind the drill bit to give it a negative rake and make the cutting edge one sixteenth of an inch thick. The point of the drill should be cut down to widen the angle. These precautions will prevent any tearing or chipping. While drilling (at a slow speed), clean the hole frequently to release any gas which might be produced by machining. Don't stop the drill in the plastic, otherwise the material might freeze on the drill. The plastics surrounding the drill will expand through frictional heat and shrink as it cools. Because of this, the hole drilled will probably be smaller than the drill used.

To saw plastics a jeweler's saw is admirable, but inadequate for fairly thick stock (over 3/8" thick). An open tooth blade (no more than ten teeth per inch for the thicker plastics) should be used, preferably on a band saw. It is best to remove the "rake" from a blade to prevent any chipping.

Filing is done with any metal files, from a bastard to a very fine cut. A good file to use on a flat surface is a vixen file, which has an almost planing action.

Polishing proceeds through the same steps that most metalworkers are familiar with. After filing, a cutting paper such as silicon carbide is used, starting with 240 grit, then 320, 400 and finally 600 grit. When all scratches have been removed by the successively smoother papers, the plastics may be buffed either by machine or by hand. Industrially an intermediate step between sanding and polishing is used called ashing. Pumice and water are applied to the plastic piece by means of a wheel. To buff, a clean unstitched muslin buff on a wheel impregnated with compound will give a beautiful luster. Care must be taken to avoid burning or melting if the wheel is rotating too fast or if the plastic piece is held too long to the buff. Most metal buffing compounds will work for plastics, but are difficult to remove from the finished piece. Special anti-static plastic buffing compounds are available which leave a high polish; any residue will easily wipe away.

There are several methods used to bond plastic to plastic; only one or a few may suit each plastic best. Again, a guide should be consulted for each specific material. A solvent may be used which is a cement that dissolves or softens the surfaces to be joined and after joining dissolves away. Dope is a cement which is a solution of the plastic to be bonded in a solvent. This is best for imperfectly fitting parts made of the same plastics. Polymerizable cements are monomers compounded with catalysts which polymerize below the softening point of the materials to be joined.

Welding is done with hot gas rather than a flame. The welding temperature must be high enough for proper softening but low enough to prevent thermal degradation or burning. The welding rod is the same composition as the material to be joined, and a welded joint is usually as strong as the material itself.

The fastening of plastic to metals is perhaps best accomplished mechanically. For instance, a rigid plastic may be tapped and a metal screw inserted. When the hole to be tapped in a plastic is drilled, care must be taken to make sure a drill of the correct size for a particular tap is used. Also when tapping, turpentine may be used as a lubricant.

Drivescrews are an excellent device to fasten metal to plastic. (Fig. 1) A drivescrew is a spiral-ribbed metal cylinder with a threaded interior which is made to receive a particular screw. A hole is drilled in the plastic to accomodate the length of the screw which is the same thickness of the unthreaded section. A light hammer tap drives the drivescrew in place. A number 55 drill is good for most standard drivescrews.[9]

Riveting plastic to metal is not much different from riveting metal to metal. However, if the plastic is somewhat brittle (such as an acrylic, like 'Plexiglas') the hole drilled should be exactly the same size as the rivet, if not somewhat larger. This will prevent cracking as the rivet expands. A somewhat resilient plastic will allow for some expansion of the metal; thus with a plastic like a polyacetal ('Delrin') the metal can be force-fit in place before riveting. After the hole is drilled, it is countersunk, the pieces assembled and riveted together.

Bolts can be used with no special problems, and in some plastics a wood screw will work beautifully. When using a wood screw, the plastic must

[9]Arthur Dunham, Working with Plastics. p. 58.

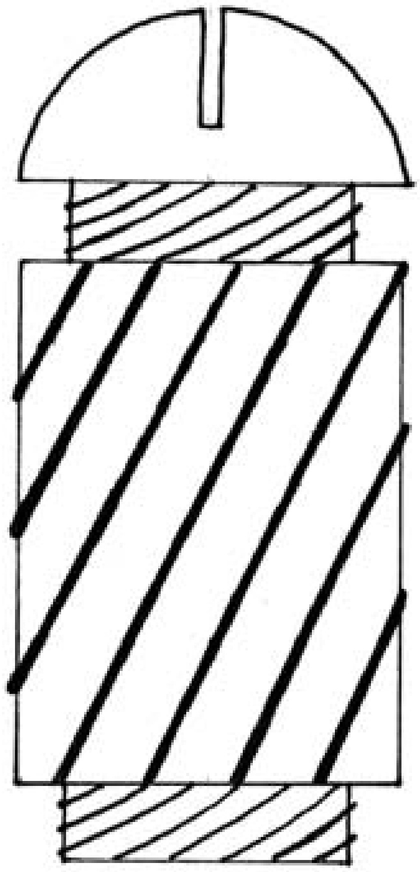

Fig. 1: Drivescrew

be able to accept the screw without cracking. Of course, a pilot hole is drilled having the same width as the unthreaded portion of the screw.

Cement will bond plastic to metal, an epoxy being the best chemical bond for metal. All surfaces must be cleaned and lightly scratched. However, some plastics do not adhere well to epoxy, and again a guide for each specific plastic should be consulted. For many plastics a specific cement is made for specialized use.

CHAPTER II

THE APPLICATION OF PLASTICS TECHNOLOGY TO AN INDIVIDUAL'S MANNER OF WORKING

Plastics Qualified by Personal Design

The many different products made available by the plastics industry offer a wide variety of materials to someone interested in working with plastics. For the most part I chose to investigate the engineering plastics - " . . . certain thermoplastic polymers with very good mechanical, electrical and chemical characteristics which are dimensionally above average in stability, particularly at elevated temperature. These plastics are suitable for many applications where they replace metal and where they have the advantage of better resistance to chemicals."[10]

Being trained as a metalsmith, why work with plastics? And with so much to choose from, why be confined to one group of plastics? As much as material limits design, design limits material, and at this stage in my education the importance of developing a personal design is very great.

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[10]Lionel K. Arnold, Introduction to Plastics, p. 130.

William Morris asserted " . . . that the presence of any beauty in a piece of handicraft implies that the mind of the man who made it was more or less excited at the time, was lifted somewhat above the commonplace; that he had something to communicate to his fellows which they did not know or feel before, and which they would never have known or felt if he had not been there to force them to it."[11]

For the past year or so I have been interested in working a material subtractively - piercing and carving through mechanical processes such as drilling, sawing and filing. By nature it is a slow process, proportional to the ease with which a particular material can be worked. Plastics, especially the engineering plastics, can be filed, sawed and drilled readily with the same tools and knowledge that are applied to metals. Because of the waste resulting from a subtractive process, working this way in non-ferrous metals (especially the precious metals) is a fairly expensive proposition. Historically other materials have been sought out to render certain forms when working directly with a material subtractively. Wood and bone have been used traditionally in combination with metals as handles, nobs and decorative elements. In the past century,

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[11]William Morris, <u>Some Hints on Pattern Designing</u>, p. 8.

however, science and industry have produced a material which can be used with metal, and sometimes even replace it! Thus, as a product of society and being affected by the age in which one lives, it seemed appropriate for me to explore the plastics. Here was a material which would allow for a development of personal design and an opportunity to gather knowledge and apply what was developed for mass production to one's individual manner of working.

Perhaps the singlemost factor that distinguishes a craftsman from a fine artist is that the craftsman works within the confines of an object (whether a teapot, piece of jewelry, rug or chair). He has a vehicle within which he finds expression. Therefore a craftsman's choice of vehicle is as important as one's choice of material. Within the past century there has developed a popular demand for objects which are decorated. The industrial revolution made these items available to people everywhere, whether purchased in stores or bought through catalogues. The Victorian era governed style, and everyone wanted decorated objects to adorn tables and desks as well as having paintings on their walls. Though he was not producing for the populace, Fabergé responded to this new need of society for objects of fantasy, and accordingly switched his emphasis away from objects of personal adornment. But still the craftsman steered from making purely sculptural form - his vehicle had to have a purpose.

As a craftsman I chose to work within the confines of desk objects. At the same time that the metalsmith began to make decorated objects for purposes other than eating or personal adornment, plastics were born. Thus plastics are combined with metal in objects that have a function, yet are highly decorative. For, as Morris said when speaking of a craftsman's decoration, "To give people pleasure in the things they must perforce <u>use</u>, that is one great office, to give people pleasure in the things they must perforce <u>make</u>, that is the other use of it."[12]

In all of the projects made for this thesis some general problems were encountered. Perhaps the greatest is that plastics are produced by and for industry, not the individual. Many of the processes developed for working with plastics are inapplicable because of cost and equipment needed. Adjustments must be made and certain processes

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[12]William Morris, <u>Selected Writings and Designs</u>, Asa Briggs, ed., (Baltimore, Md., Penguin Books, 1962), p. 86.

avoided because they are not practical. For example, one great feature of plastics is that they can be produced in many colors. However, to find colored plastics available to an individual, especially the engineering plastics, is almost impossible. Color lots are usually made to order in amounts that far exceed anyone's budget or use. Or, for instance, all plastics are combined resins and catalysts and are molded or cast in some form. Yet, for an individual with minimal equipment, he will find only two kinds of plastics that can be cast fairly simply (epoxy and polyester resins).

Adjusting to problems such as these is a necessity if one is to advance beyond simply purchasing the available material. When actually fabricating the piece I found that greatest consideration should be given to how the plastics and metal will be joined. For instance, if the joint will take any amount of stress, chemical fusion (i.e. cement) is not adequate. From its inception a design should take into account the fitting of pieces together. Information in books will suggest certain solutions, but each piece presents peculiar problems.

The following is an explanation of how each piece was made in the production of this thesis, the problems that evolved, the solutions reached, and some possible alternatives to those solutions. It is assumed that the reader has a working knowledge of metalsmithing techniques; therefore I will dwell on the problems peculiar to plastics and the joining of plastics to metal.

The Individual Projects: Methods of Fabrication

Letter Opener

Polycarbonate Handle, Cast and Forged Silver Blade, Copper Electroplating

Polycarbonate ('Lexan') is a clear, transparent plastic with either an amber or blue tint. A very tough plastic, it has high tensile strength and good ductility, "behaving rather like a metal."[13] It retains its properties over a wide temperature range, is dimensionally stable, virtually self-extinguishing and has a high softening point. Polycarbonate is an ideal engineering plastic, a nail of which can be driven through two inches of wood![14] Its chief drawbacks are high cost, (common to the engineering plastics), pale yellow or blue tint, and susceptibility to crazing under strain. For this specific project I chose polycarbonate for its acid resistance, as it was to be placed in a sulphuric acid bath for copper plating.

Polycarbonate is an excellent machining material. I started with a one inch plate of this

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[13] E. G. Couzens and V. E. Yarsley, Plastics in the Modern World, p. 90.

[14] Ibid., p. 90.

plastic and used a bandsaw to cut out the basic form. The blade was one-half inch wide with ten teeth per inch, running at 3000 FPM (feet per minute). To pierce this block, it was first drilled with a drill bit having a wide angle point rotating at 300 RPM. The drill was withdrawn several times during the operation to let any gasses escape. A wax blade (spiraled jeweler's saw blade) was inserted in the drilled hole and the inner shape cut out.

The block shape was then filed with successively smoother metalworking files, starting with a mill and a bastard, working up to finer cuts. (A wood rasp can be used initially to remove large amounts of material.) Refining was begun with 100 grit aluminum oxide paper and then taken to 240, 320, 400 and 600 grits silicon carbide papers.

Polycarbonate polishes beautifully. The majority of the handle was buffed with bobbing compound and a wool buff rotating at 3500 RPM. With a little care this will not melt the plastic, and it is a good deal faster than buffing with a loose buff at a slower speed. The inner contour was buffed by hand. A polishing cloth was impregnated with bobbing compound and rubbed briskly through the inner hole. As opposed to the outer surfaces, this inside shape was finished first with 600 grit.

The entire piece was cleaned with ammonia and soapy water, then buffed with plastic buffing compound. This insures the removal of all bobbing compound (which is difficult to clean from the plastic) and gives a high luster. Used by itself it is not as abrasive as bobbing compound or tripoli, but it is greaseless, anti-static and easy to wipe off.

The entire handle was then clean, but it had a definite blue cast which on a smaller piece would not be noticed. It was therefore decided to sandblast the handle and this worked very well, giving a frosted surface and toning down the bluish hue.

The plastics piece was then ready to attach to the silver blade, which had been forged from seven guage sheet. Two decorative silver caps, made to contain the ends of the plastic handle, were cast and soldered onto the blade. These caps were hollowed to receive the polycarbonate ends, which are held in with epoxy. It would not be a strong joint if the plastic and silver surfaces merely met and were cemented together; therefore the plastics piece was made to fit into the silver caps. (Fig. 3)

A filled epoxy was used, which sets in four hours and cures in twenty-four. The epoxy was mixed and placed in the hollow silver caps, then the polycarbonate handle was inserted and tied in place (to prevent it from shifting while setting.) There was a small stepped space between the handle and the silver cap, (Fig. 4), so something had to be done to make a smoother transition. A 'B-stage' filled epoxy[15] was used to fill and build up around the gap. When the epoxy cured and the two pieces were joined, the piece was ready to electroplate.

The design had already deviated from the original drawing, and my plans for electroplating changed accordingly. I enjoyed the translucency of the polycarbonate and wanted to maintain the sensual feeling of the fluting in the handle. Also, the transition between the blade and handle had to be plated to cover the grey epoxy used to fill the gap. I therefore decided to plate the joints and make two bands of copper between the fluted and smooth sections of the handle.

To prepare a piece for electroplating all parts must be clean and the areas of any non-conductive parts to be plated painted with conductive

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[15]When liquid resins are mixed with catalysts they go through three stages. The first 'A-stage' describes the initial liquid state of the mixture. After a while the mixture is pliable but can be cut and maintain that cut - this is referred to as 'B-stage'. The final hardened product is termed 'C-stage'.

lacquer. (I used Electrodag 416 from Acheson Colloids.) For a plastics piece a lacquer (and its solvent) must be chosen which will not dissolve the plastic. All conductive parts such as silver must be masked, except for those areas where plating is desired. In this project ordinary nail polish was used to mask the silver, but since nail polish remover contains methyl ethyl keytone, which will dissolve several plastics, it is important to put the polish only where it can be removed without harming the plastic. Otherwise, another masking agent must be found.

Conductive lacquer completely covered the epoxy joint (which might dissolve in the acid), and was painted onto the polycarbonate. When painting the lacquer onto a plastics piece it must be kept in mind that whatever design applied will be metal, with essentially nothing adhering it to the plastic except the form itself. The painted design should at some point totally surround the piece or grip an undercut, or else it may easily fall off. Also, any linear elements may lift away.

To electroplate, all areas to be plated must be attached to the cathode. Since the conductive lacquer which surrounded the caps was painted up to and touched the silver caps, a contact was made between the lacquer and a conductive material. A wire was run off the tip of the blade (which was left unmasked) and wrapped around the cathode, a relatively simple procedure. Attaching the area to be plated at the top of the handle to the cathode was a challenge, however. The plastic could be drilled where painted, a wire force-fit into the resultant hole and a contact established from the wire to the conductive lacquer on the plastic. But removing the wire after plating would either leave a hole or an unsightly stub where it would be cut off. It was decided to make a work-hardened metal strip with pointed ends which would surround the handle and grip either side of the painted plastic with its points. (Fig. 5) This clip then had a wire wrapped around it and run off to the cathode. The entire piece was placed in the bath, with the exception of the unmasked end of the silver blade. The wires running off the end of the silver blade and the metal clip were attached to the cathode. Plating began and was maintained at a fifty-five second plate and a five second deplate at .7 volts.

Especially when using a conductive lacquer the process must be checked several times during the first half hour or so. Sometimes the piece must be painted several times to establish a complete initial plate. It is the nature of the conductive lacquer that the metal will settle out of solution, and perhaps the first coating will be uneven in terms of conductivity. If after several minutes the painted surface is not plated in some areas, then merely repaint those areas with thoroughly mixed lacquer and replace in solution. If it hasn't plated at all, the contact is poor and a new contact must be made.

After several checks the plating of the letter opener was going well, and in about four hours the areas connected by the end of the blade to the cathode were finished. However, plating is slower using a metal clip, and the area under the fluting on the handle had to be continued for three more hours. I simply removed the contact to the blade and replaced the piece in the bath, with a contact only to the clip.

When plating was complete the copper was oxidized, the nail polish removed, and the silver and copper areas were buffed. After scratch-brushing the metal, the piece was finished.

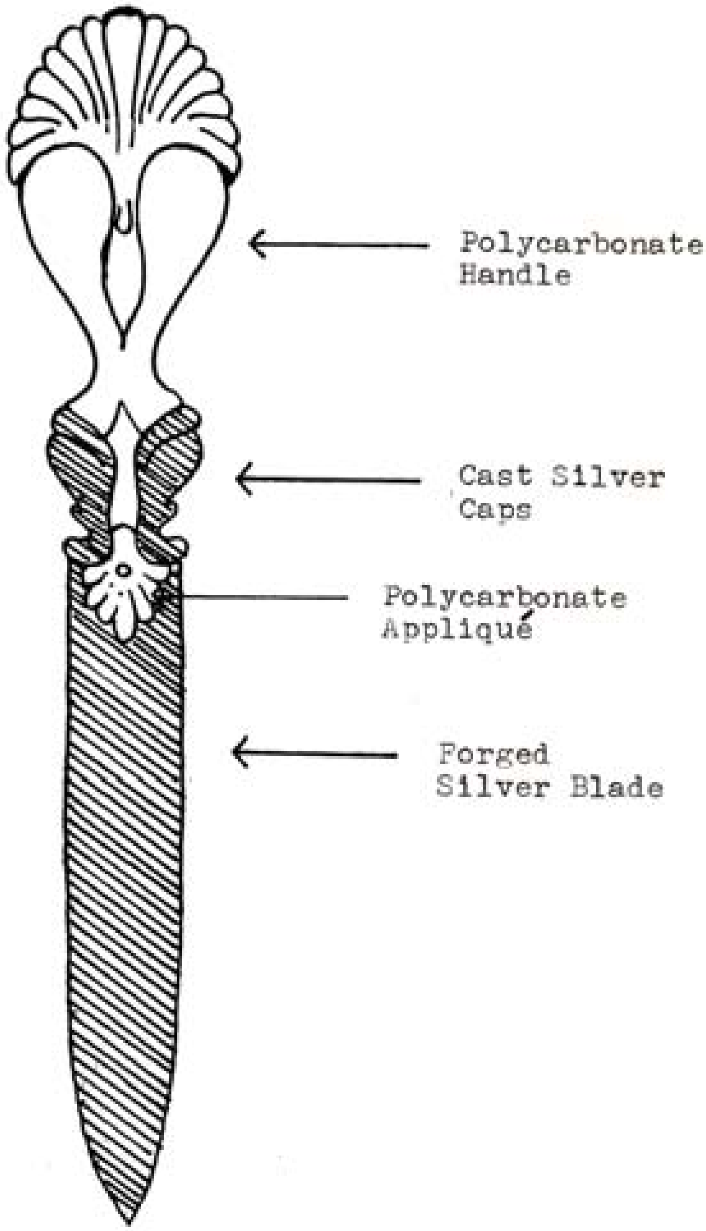


Fig. 2: Letter Opener (Working Drawing)

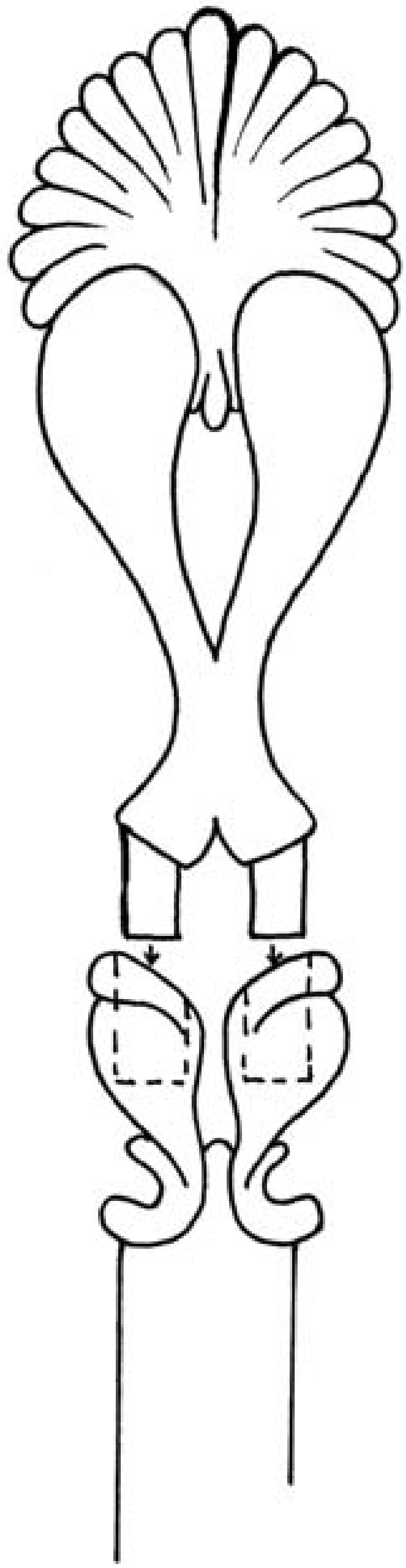


Fig. 3: Fitting of Handle into Caps

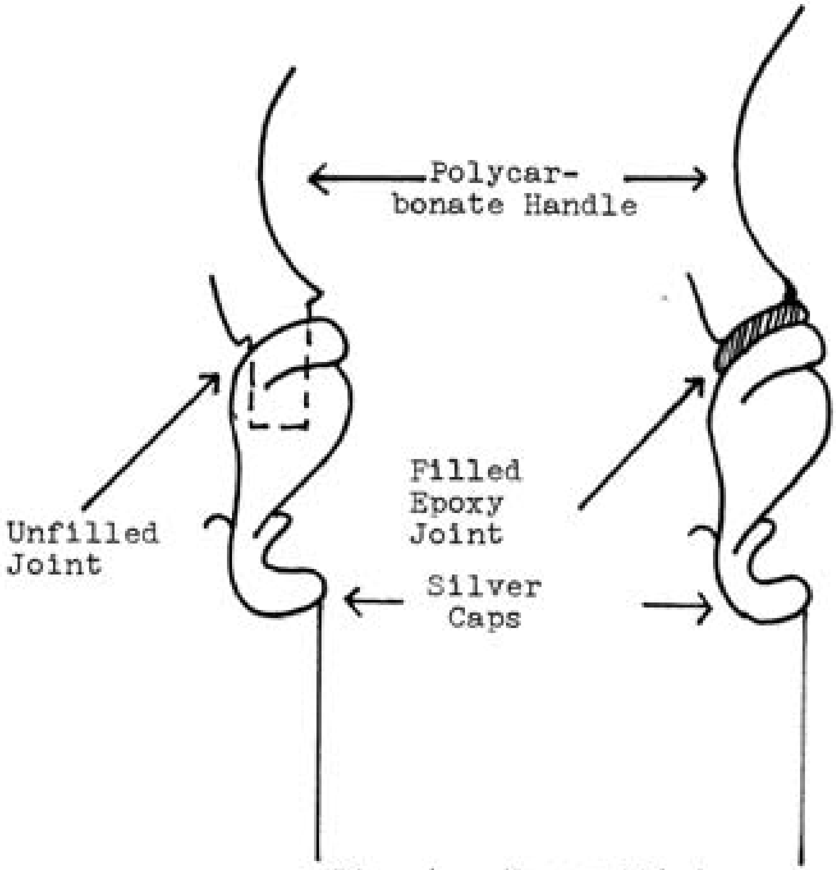


Fig. 4: Epoxy Joint

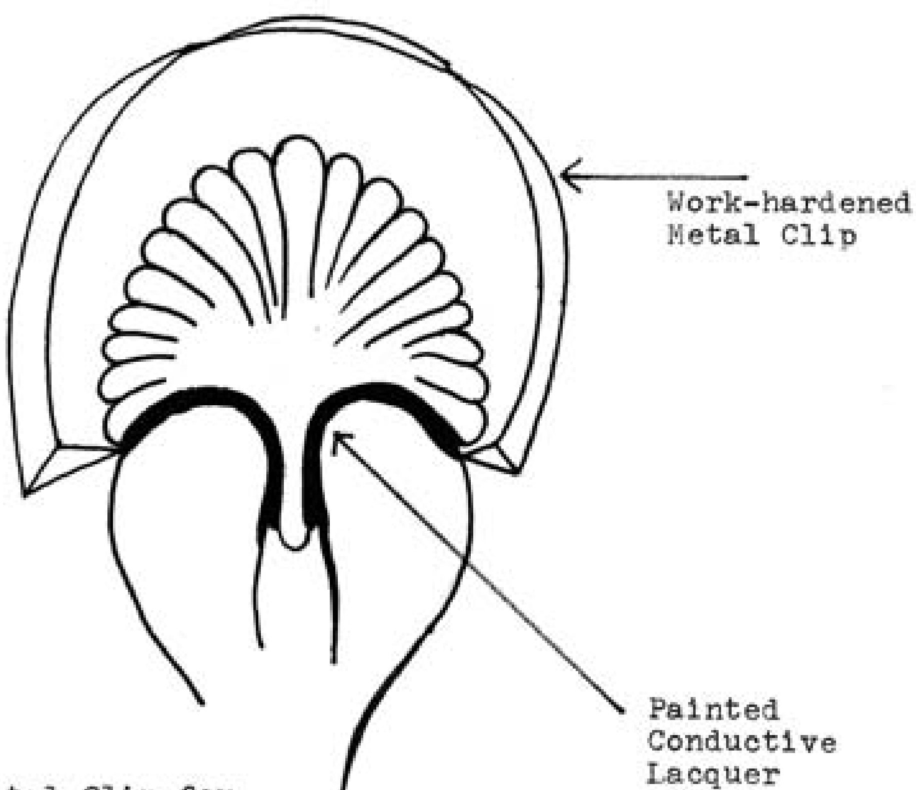
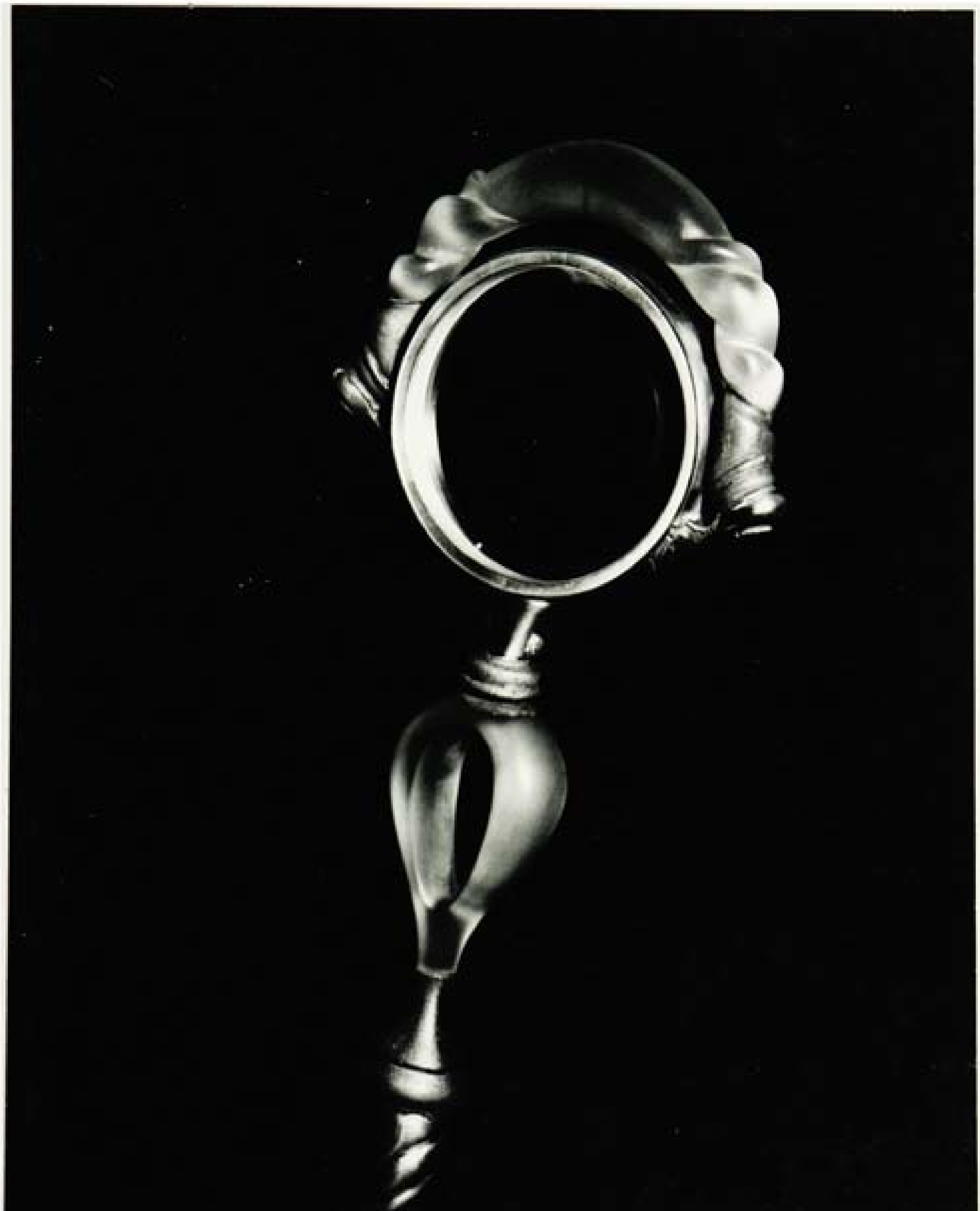


Fig. 5: Metal Clip for
Electroplating



Magnifying Glass

Polycarbonate Crown and Handle, Silver Fabricated Rim and Lens Mount, Cast Silver Cap and Tail for the Handle, Cast Silver Shoes for the Crown

Made as a companion to the letter opener, the processes involved in working with polycarbonate for the magnifying glass were pretty much the same. However, the design called for some different solutions in attaching the polycarbonate to the silver.

To attach the silver tail to the handle, the same principle was used as in the joining of the handle to the silver blade of the letter opener. A male part (the handle) was inserted into the hollow, cast silver female tail, which was coated on the inside with filled epoxy. (Fig. 7) The pieces were mechanically held in place until the epoxy cured.

I wanted a very strong joint between the polycarbonate handle and the rim of the magnifying glass, for it would have to take much stress when the glass is held. Even though the silver cap to receive the handle was hollow and the handle force-fit the cap, I thought a bond of epoxy was not enough.

Therefore, after the handle was epoxied inside the cap, a hole was drilled through both pieces perpendicular to the line of center on the handle. (Fig. 8) Since epoxy dissolves with heat, the drilling was done very slowly. I was drilling through a fairly thick combination of plastic and metal, so it was necessary to proceed in such a way that the drill would come out exactly opposite the point from which it entered. On either side of the silver cap a "punch" was made for the drill with a scriber and the point of a scraper. To keep the two points aligned and to insure straight drilling, these steps were followed:

1. A board with a nail extending about 1 1/2 inch by its pointed end was clamped to the drill table with the pointed end of the nail directly in line with the point of the drill bit.

2. The piece was held so that one of the scribed punches rested on the nail and the other was directly beneath the drill bit.

3. Slowly, a hole was drilled not quite half way through.

4. The piece was turned over so that the half drilled hole rested on the nail, and once again a hole was drilled not quite half way through, starting at the scribed punch.

5. The piece was then hand held and the small amount of material left in the middle drilled out.

After the hole was drilled, the ends of the hole were made slightly larger with a scraper; then a snug fitting silver wire was riveted in place.

Before the final assemblage of the piece, the polycarbonate crown had to be attached to the cast silver shoes, which were soldered onto the rim. In order to insure a secure fit, it was decided that both the crown and the shoes, after epoxied, would be drilled, tapped, and a silver screw inserted.

It was a simple plan with several complications. Firstly, the silver shoes were not hollow; the surfaces of the silver and polycarbonate were only flush to one another rather than fitting one inside another. It has been mentioned before that this is structurally inadequate. I proceeded, however, in epoxying the crown in place and, after the epoxy was cured, began drilling. Unfortunately the silver shoes should have been drilled before the crown was epoxied on. During the first attempt at drilling the drill bit broke off in the silver, and, because the plastic was already attached, I couldn't solder the hole shut. I would now have to rely on electroplating this area to cover the hole.

In my second attempt at drilling so much heat was generated in going through such thick metal that the epoxy joint dissolved. The crown had to be epoxied in place again and drilling was attempted a third time. Originally the whole piece was placed in a table vise, clamped between two pieces of soft wood touching the metal rings only. However, this allowed the piece to move slightly. It became necessary to hand hold the piece and press it onto the slowly rotating drill bit. Going very slowly and withdrawing the drill often, a hole was finally successfully drilled through both shoes and into about 3/4 inch of polycarbonate. (Fig. 9) Snug fitting, work-hardened silver wires were merely epoxied in both holes and the crown was attached.

All joints between the polycarbonate and silver were electroplated as before, using conductive lacquer to plate onto the plastic parts and cover any epoxy in the joints. Nail polish was used to mask out all silver areas not to be plated. The copper was oxidized, the piece cleaned and scratch-brushed, the magnifying lens placed between two rings which were force-fit in the rim, and the piece was done!

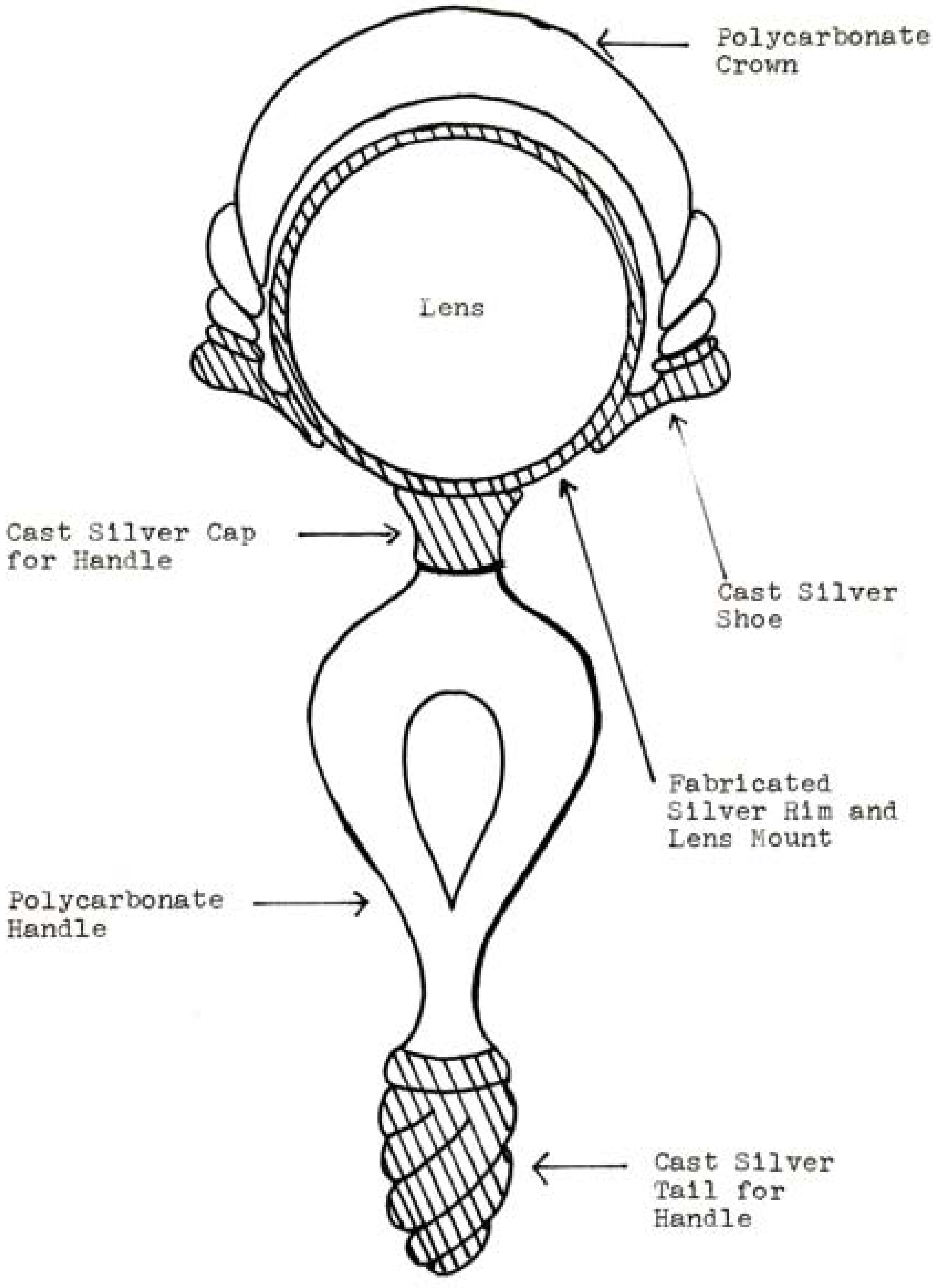


Fig. 6: Magnifying Glass (Working Drawing)

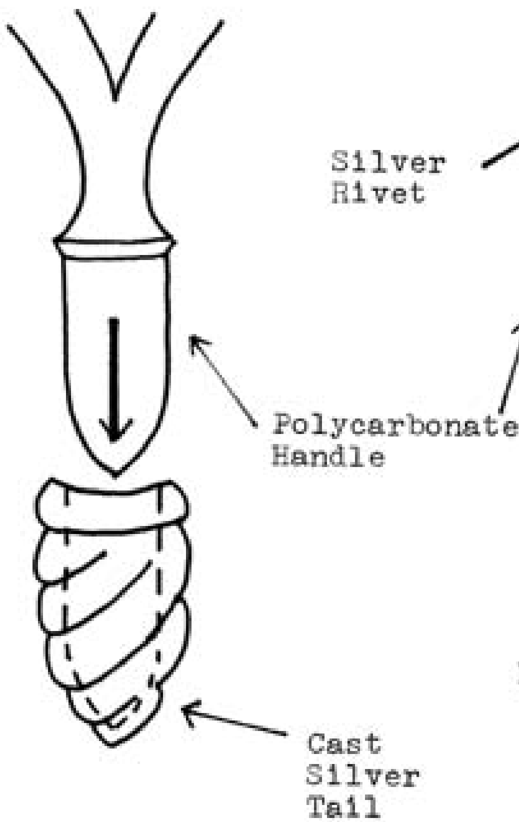


Fig. 7: Fitting of Handle and Tail

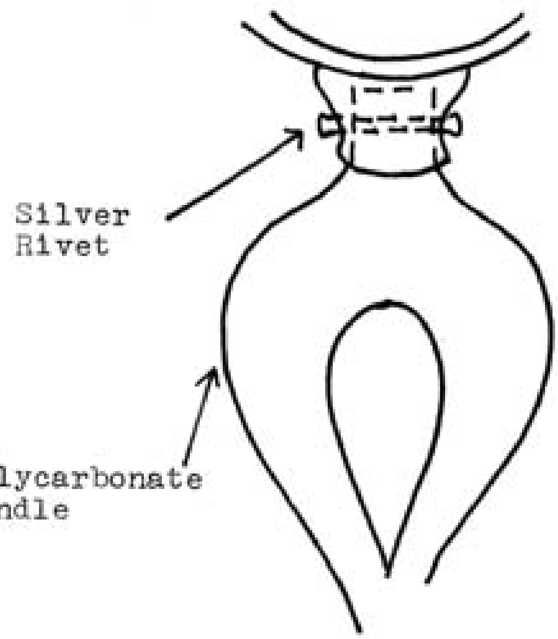


Fig. 8: Fitting and Rivet of Handle and Cap

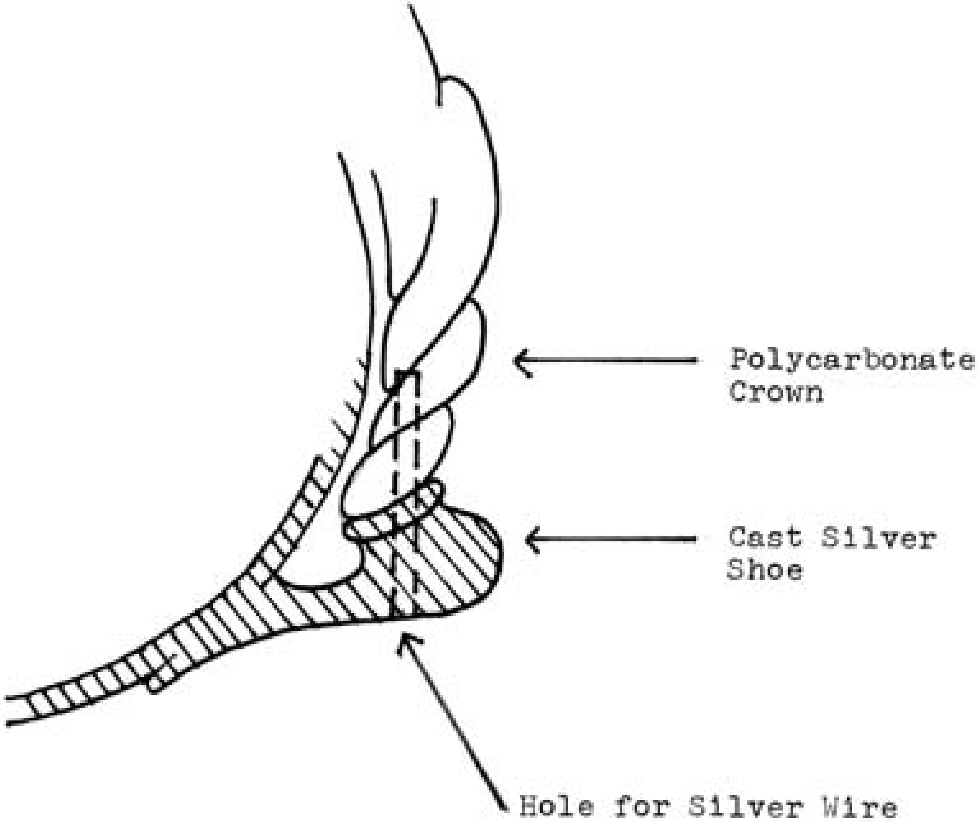


Fig. 9: Crown and Shoe with Hole for Silver Wire

Paperweight

Fabricated Copper Sheet, Polyamide (Nylon), Brass Rivets, Copper Electroplating

The polyamides and their copolymers are now commonly referred to as nylons, an excellent example of tailor made plastics. There are many different nylons, but four principal types should be described:

1. Nylon 66 has the best mechanical properties, but is the most difficult to process. It is usually produced as a fiber, but can be extruded in rods or tubes, being very tough, and having a low coefficient of friction, but allowing a relatively high amount of water absorption.

2. Nylon 6 is softer and less stiff than nylon 66 and easier to process, but has inferior mechanical properties and a high water absorption.

3. Nylon 11 is very resistant to weathering, has lower water absorption, and is more easily produced. However, its mechanical properties are inferior to those of nylons 6 and 66.

4. Nylon 12 is the newest nylon in importance, with a lower melting point, less water

absorption and greater dimensional stability under changing humidity.

Nylon is a versatile engineering plastic, and each number is qualified by different properties. As a whole nylons are fairly expensive but used where toughness, rigidity, abrasion resistance and reasonable heat resistance are important.

Nylon was chosen for this project because of its handsome appearance (almost like ebony), its toughness and good mechanical properties.

In working with a nylon, its fibrous structure becomes something to be reckoned with. Whether sawing or filing, a drag is left when machining. I started with a 3/8 inch sheet, cutting on a bandsaw with a 1/2 inch blade having 10 teeth per inch and going 3000 FPM. It seems that fewer teeth per inch will tend to minimize drag, and as few as four teeth per inch will work admirably.

The two pieces of nylon forming the outer "wings" of the paperweight were cut out and needed to be shaped. To obtain the inner contour, a flexible shaft and rotary files with a fairly open cut were used. This roughed out the inner relief areas, which were then worked with various riffle files. The outer areas were carved with regular metalworking files, from coarse to fine cuts. Then the entire surface was refined first with aluminum oxide paper, switching to silicon carbide 320 grit and proceeding to a 600 grit finish.

Buffing nylon is a trick, probably because it is so resistant to abrasion. The metal buffing compound did not work well at all and was impossible to remove. However, the plastics compound worked pretty well, using a loose cotton buff at a high speed. (The low speed seemed ineffective.) I found there were some areas of the piece which were easily worn away in buffing and very difficult to polish to a smooth surface. As a result, I was not very successful in getting a perfectly finished surface. Perhaps the presence of an inner relief was a hindrance in the buffing process, for there was little problem in buffing the outside areas. At any rate, the pieces were sandblasted, which gave them a uniform surface quality.

The nylon pieces were finished and ready to attach to the copper body. Thick copper plate (3/8 inch) was machined to form three pieces - two antennae and the middle, fluted body. All three were soldered onto a 1/8 inch thick sheet cut to support the entire form, nylon included. The original plan was to simply rivet the nylon parts onto the bottom sheet with commercial round-head copper rivets. I finally found some brass round-heads and decided to proceed.

To rivet the nylon to the copper, the plastic pieces were first held in place on the sheet with small stitches around the edge. Holes were then drilled the exact size of the thin stem of the rivet into both the nylon and copper simultaneously. As the plastic could not shift out of position, all holes could be drilled before insertion of the rivets. The nylon was removed and the holes in the plastic were made somewhat larger to allow for expansion of the rivet and thus circumvent any cracking that might occur.

The holes on the bottom of the metal sheet were countersunk. In addition, to receive the domed rivet head, I decided to countersink the top of the holes in the nylon. This was a problem. Due to the curvature of the contoured nylon, the countersinking of the holes was not on center, and an irregular space appeared around the edge of the domed head when the rivet was in position. (Fig. 11) To prevent this, the rivets should have been placed where the curving of the contour was very slight. If any fitting to the curve must be done, then the underneath portion of the domed head could perhaps be filed (Fig. 12) to fit a rounded surface rather than attempting to countersink.

However, care must be taken not to remove too much metal from the rivet head, as it might look more like an oval than a circle when set in the piece.

The rivets were positioned in the piece, and set by resting the domed head on a piece of rosewood and hammering with a rivet hammer from the back of the piece. This prevented any damage to the dome from hammering. The piece was refined, the edges filed up to the nylon sections and buffed.

After this was done the irregular areas around the heads were painted with conductive lacquer which partially covered the brass rivets. The entire piece was placed in a copper plating bath and the rivets, their surrounding irregular areas, and the outer edge of the entire piece were plated.

Nylon is not damaged in a sulphuric acid copper plating bath, but it is an absorbent material, and should be soaked in an ammonia and water solution after plating is finished. After soaking in several clean water baths the nylon was free from any residue; the piece was oxidized, lightly buffed and finished.

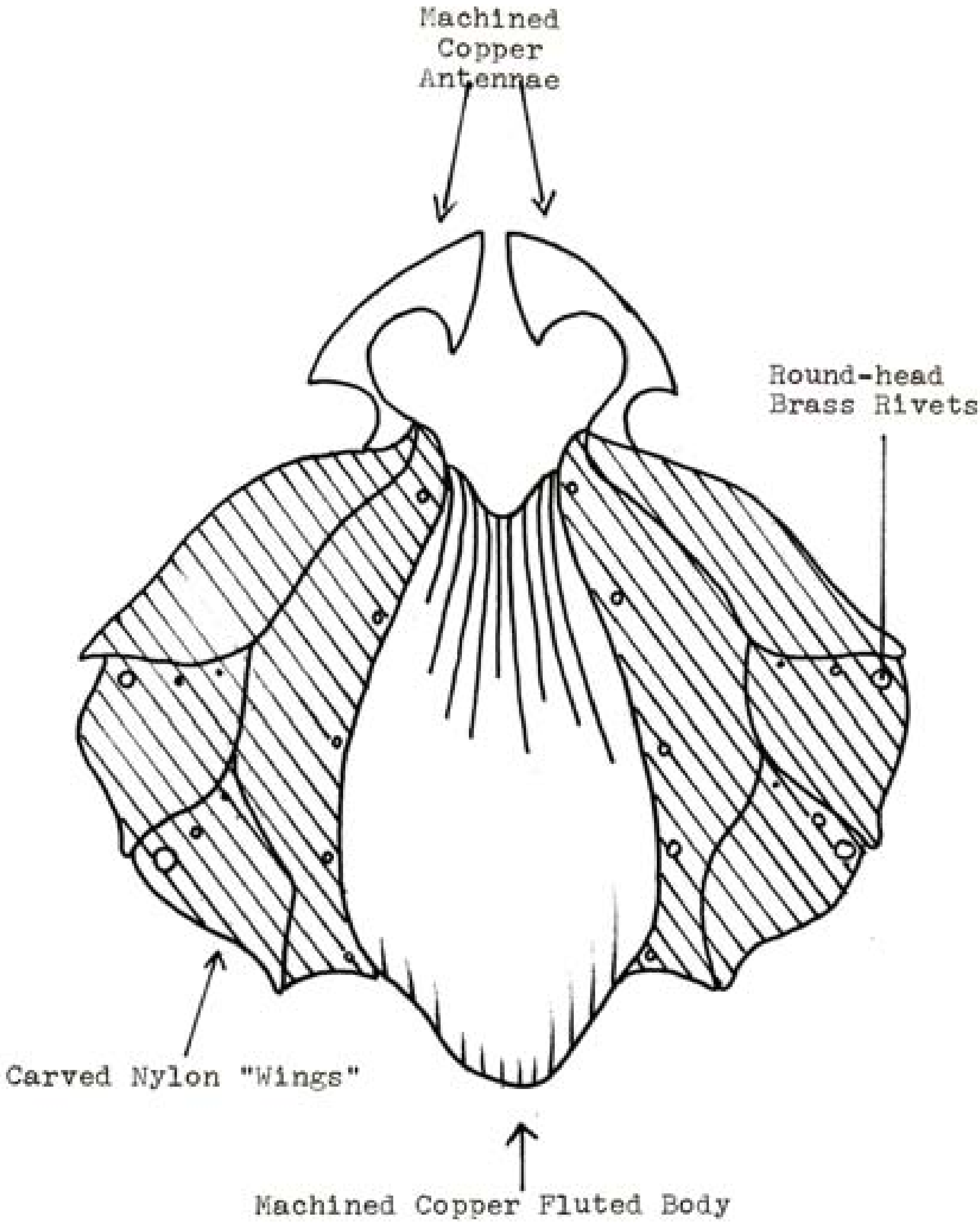
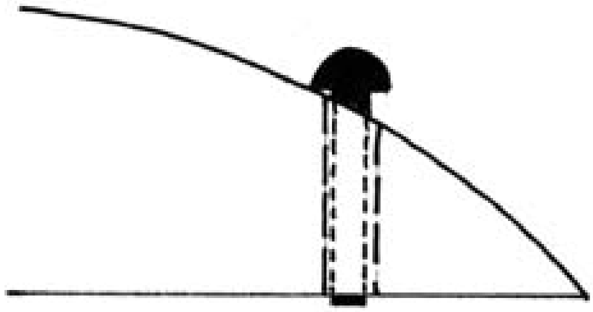
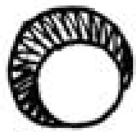


Fig. 10: Paperweight (Working Drawing)



Round-head Rivet on a Curved Surface

and



Consequent Irregular Space
Resulting from Countersinking
a Round-head Rivet on a
Curved Surface

Fig. 11.

Filed Round-head
Rivet

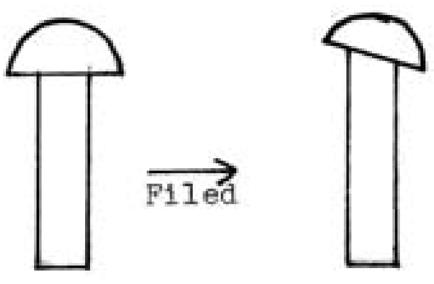


Fig. 12

Rubber Stamp, (Frontispiece)

Epoxy Resin Handle, Polymethyl Methacrylate ('Plexiglas') and Silver Base, Rubber Stamp

The properties of any cross-linked resin depend on the curing system used. For epoxy resins a large variety of hardeners are used affecting flexibility, adhesion and chemical resistance. In addition to the versatility of curing systems available, epoxies are tough, have low cure shrinkage, good adhesion to other materials, (especially metal), good alkali resistance, high dimensional stability, low water absorption and good heat resistance. Its greatest drawback is high cost. I wanted to cast the handle (Fig. 14) of the rubber stamp in plastic, and originally decided to use an epoxy resin for its low shrinkage rate and excellent adhesive qualities.

To begin a cast plastics piece a model must be made of some material that can be embedded in a silicone rubber compound and can withstand some heat due to catalyzation of the rubber. Wood, plaster, plastic, or any other suitable material should be used for the model. I used a dental stone, which is similar to plaster. Since it comes in a powder form and is mixed with water, a container must be made in which the mixture will set up. It should be somewhat larger than the design from which the model will be carved. A cardboard box was constructed, and the mixed dental stone poured into the mold, which was allowed to set up overnight.

The next day the cardboard was removed from the hardened dental stone, which was then filed into the shape of the handle. This material files very easily and refines well with silicon carbide paper. There was some porosity which was filled with a slurry of dental stone powder and water, then sanded down. The model was ready to be encased in a rubber mold.

Acetate makes an excellent container for a rubber mold. Thin acetate sheet (1/32 inch or 1/16 inch is fine) is cut into a strip which, when made to surround the piece, will clear all parts of the model by at least 1/2 inch. I used an elliptical tube form to surround the model, where a cone form would have perhaps been better, resulting in less waste of the rubber compound. The ends of the acetate strip were pinched together to form a tube, making a 1/2 inch seam. While the seam was held together, acetone was forced throughout the pinched area with a hypodermic needle. The acetone partially dissolves the acetate, then evaporates, leaving a permanent bond between the two ends. The ends were held together for one minute after the acetone was applied, enough time for the seam to be bonded.

Thus I had an acetate tube. The base of this container is merely a flat sheet of acetate that is attached with acetone to the bottom of the tube. A drawing of the contour of the mold desired is placed beneath a clear sheet of acetate, and the tube is held on top of that sheet, following the lines of the drawing. The edge of the tube should touch the acetate sheet all the way around. Then, by means of a hypodermic syringe, the two pieces of plastic are bonded together with acetone. For my purposes, this resulted in an elliptical container with a bottom and no top.

The dental stone model was placed in this container with the flat base of the handle resting on the acetate floor. Everything was sprayed with silicone rubber mold release.

For the rubber mold I used General Electric Silicone Rubber RTV (room temperature vulcanizing) Molding Compound No. 6. A word of warning - this product is sold by weight and not by volume, and a one pound can may only be half full. When buying, beware of the amount needed and buy enough!

The silicone rubber compound was mixed with its premeasured catalyst and vacuumed to release any air bubbles. The mixed rubber should be placed in a container much larger than its bulk, as it will expand greatly when vacuumed.

After this, the rubber was poured over the dental stone model into the acetate container. Unfortunately, I misjudged the amount of rubber needed and didn't have enough. Therefore the model was thoroughly coated with the first batch and a second batch was mixed four hours later, then poured to the top of the container. This did not present any problems.

The rubber was allowed to vulcanize overnight, and the next day the acetate was cut away. With a surgical knife the rubber mold was cut open to the model down one side, and the model was released. After washing the interior with methanol (a solvent for epoxy), the mold was thoroughly dried and bound together with binding wire and tape.

It was now ready to receive the catalyzed epoxy resin, 'A-stage'. 'Epotuf' epoxy resin was used in combination with a slow-cure hardener, used to minimize heat due to catalyzation. Before the hardener was added, however, the resin was thoroughly mixed with a colorant. To insure complete mixing, a heavy steel wire (1/4 inch), bent slightly in a "U" shape at the end, was put in a drill press and rotated at a slow speed. Using this as a mixer, the epoxy resin and colorant were thoroughly combined. The proper amount of hardener (directions for specific hardeners and resins come when purchased) was added and mixed in the same manner.

The epoxy was vacuumed, poured into the mold, and then vacuumed again. The particular hardener used was supposed to harden the resin in four days, but it catalyzed in about thirty-six hours. The plastic handle was released from the mold.

Unfortunately there was some porosity in the newly formed handle. Apparently this is not uncommon, and must be taken into consideration when planning to use plastic resins. I first attempted to fill the small holes by painting the porous surface with a new mixture of colored epoxy and sanding after it had cured. After sanding, a pumice finish was applied, but the pumice broke open the old pores and lodged in the holes. The piece was placed in the ultrasonic cleaner, which not only dislodged the pumice but opened up even more pores!

The next attempt at filling the pores involved spraying the colored epoxy onto the piece. However, the catalyzed resin was too viscous and clogged the spraying mechanism and this plan had to be abandoned.

Finally the pores were filled with an auto body putty (black in color) and sanded smooth. Then the clean piece was coated with a spray primer and painted with auto body spray paint. This gives an excellent surface, but unfortunately one sees paint and not plastic as the finished surface.

The base (Fig. 14) was made of silver and polymethyl methacrylate, an acrylic plastic ('Plexi-glas'). This plastic is water-white, but comes in a wide range of colors - available to the individual! It is weather resistant, softens at the temperature of boiling water, and is a good substitute for glass. Unfortunately it is somewhat brittle and cracks easily. However, it is a thermoplastic and can be thermoformed by the individual without sophisticated equipment.

The base for the handle is basically a fabricated silver container which holds the rubber stamp, an oval piece of mahogany with a rubber pad covering one of the flat surfaces. I wanted to separate the pink handle from the silver box, and decided to cover the top of the container with black polymethyl methacrylate. Since the top of the container was not perfectly flat, there were small gaps between the silver and the black plastic. I hoped to thermoform a piece of 'Plexiglas' to the top of the silver container.

The silver and plastic were placed in a 350° Fahrenheit kiln for 25 minutes to thoroughly heat. I then reached in with wet cloths, pressed the plastic to conform to the silver, and plunged everything in cold water, waiting for the plastic to lose its heat. My preparations for this process were inadequate as my hands simply could not force all areas of the plastic surface down. One part always stayed up. To do this properly, a softened plastic should be pressed between positive and negative molds and held in place as the plastic cools.

Realizing my rather crude process was not going to work, it was decided to adhere the 'Plexiglas' to the silver container with colored epoxy resin (black). This would fill any gaps between the silver, and epoxy is an excellent bond for polymethyl methacrylate and metal. This worked very well, and there is just a slight coloration difference between the 'Plexiglas' and the epoxy. The edges were sawed flush to the silver container with a jeweler's saw, then filed, refined with silicon carbide paper and buffed with a cotton buff and bobbing compound. The final buff was done with a plastics buffing compound and cotton buff.

A hole was drilled through the top, center, of the container, drilling both plastic and metal simultaneously - slowly! The hole was countersunk on the inside metal surface to receive a wood screw. Then the epoxy handle was drilled in the center of the flat bottom surface about two inches deep. The hole was smaller than the width of the screw. Then the handle and base were fitted together and joined by the wood screw. (Fig. 15)

A small tray was made for the completed rubber stamp to sit in; otherwise the inked stamp would be resting on the surface of a desk. A silver rim was made with an inner ring (Fig. 16). A piece of black polymethyl methacrylate was cut to fit inside the outer rim and sit on top of the inner ring. This material is very easy to cut with a jeweler's saw, but beware of cracking. The plastic was 1/8 inch thick, and I needed a piece 1/32 inch thick, so it was sanded down with No. 50 aluminum oxide paper, then refined and polished. This sheet was laid in place.

A second piece of 'Plexiglas" was cut, again to fit inside the outer rim of the tray and sit on top of the thin sheet just made. The center of this piece, however, was cut out, making a plastic rim about 1/4 inch wide upon which the edge of the stamp would rest. Thus the figured stamp pad would sit in a cavity created by the two pieces of 'Plexiglas'. (Fig. 17) The top hollow oval of plastic was held in the silver rim with colored epoxy, and this held the bottom plastic sheet in place. The tray was refined and polished; the rubber stamp pad (attached to a piece of wood) was force-fit into the silver container attached to the handle; and the piece was complete.

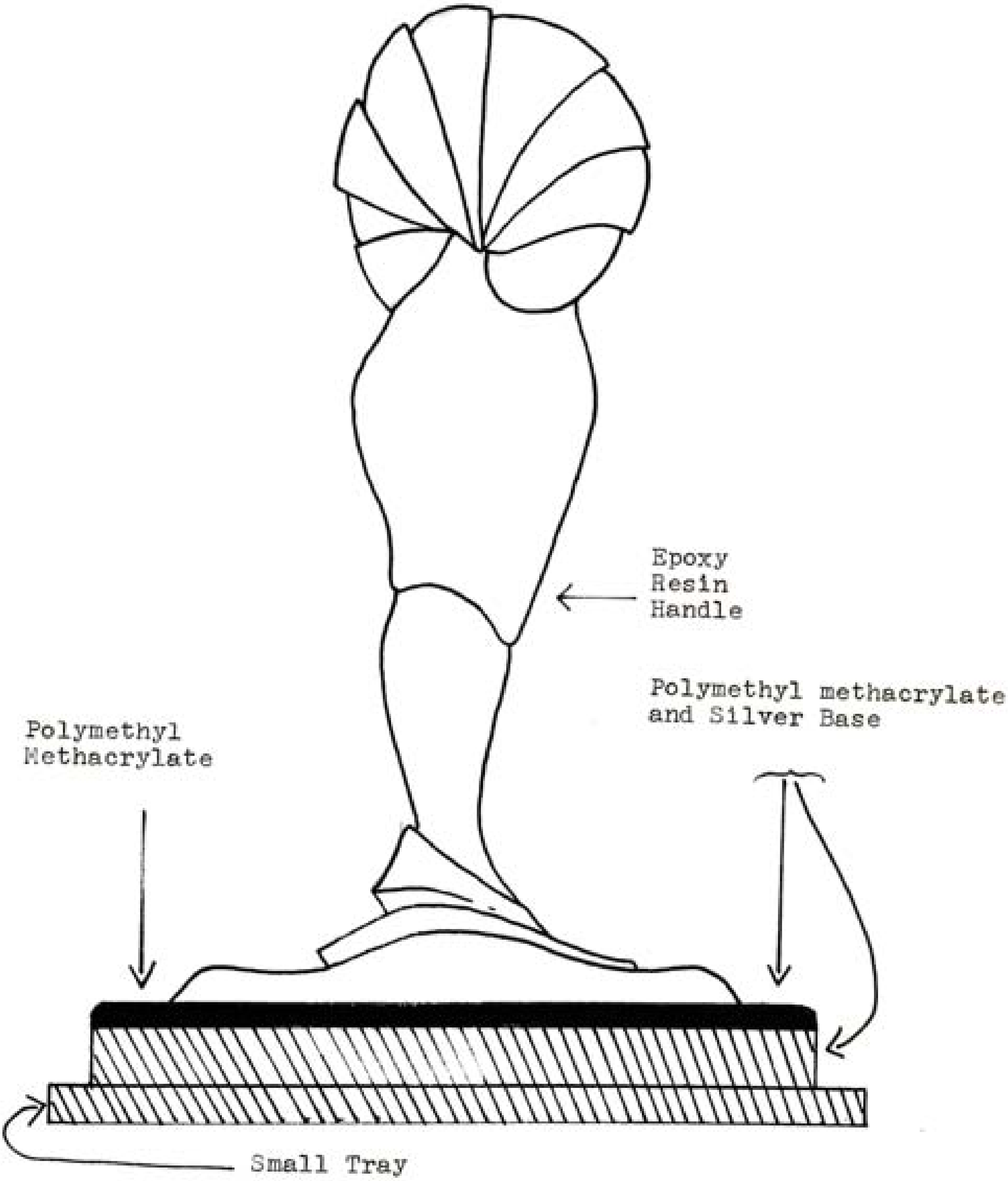
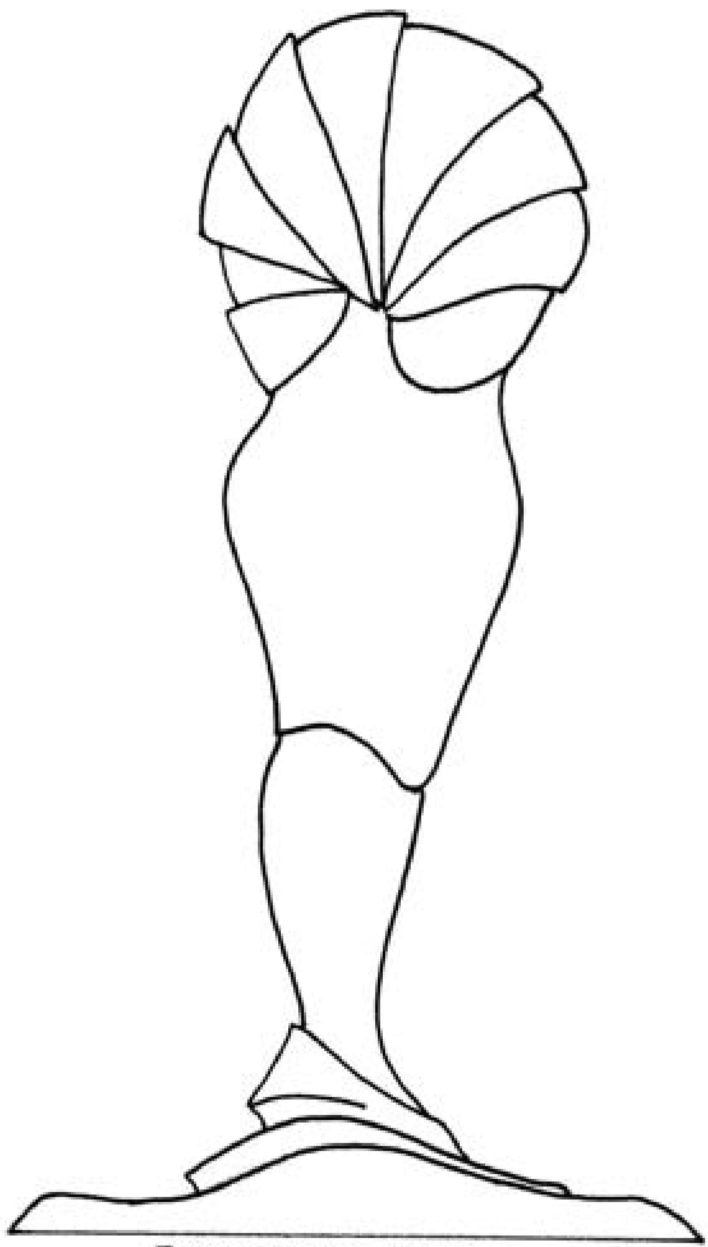


Fig. 13: Rubber Stamp (Working Drawing)



Epoxy Resin Handle

Polymethyl Methacrylate and Silver Base

Fig. 14: Handle and Base

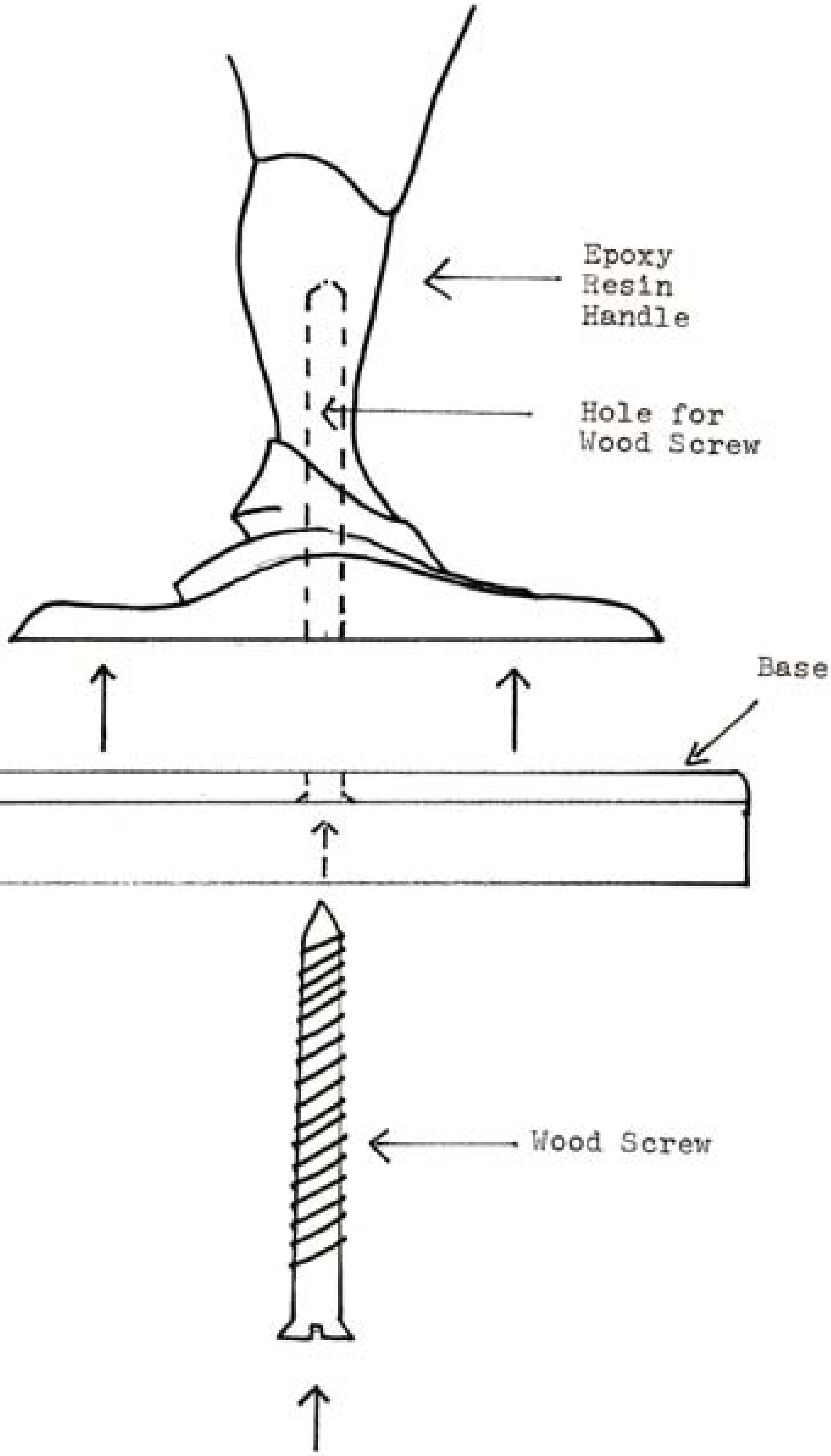


Fig. 15: Joining of Handle to Base with Wood Screw

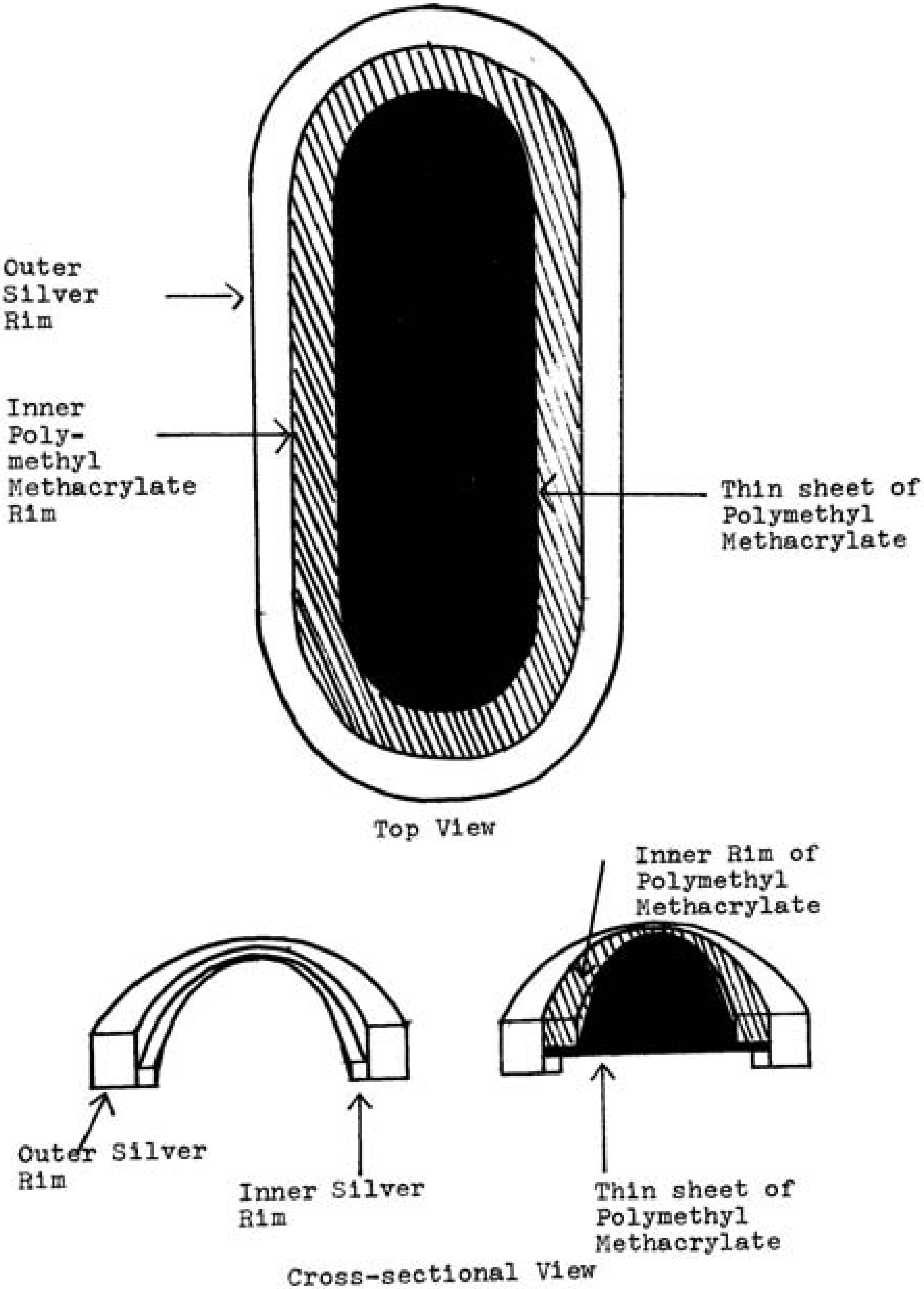


Fig. 16: Small Tray (Working Drawing)

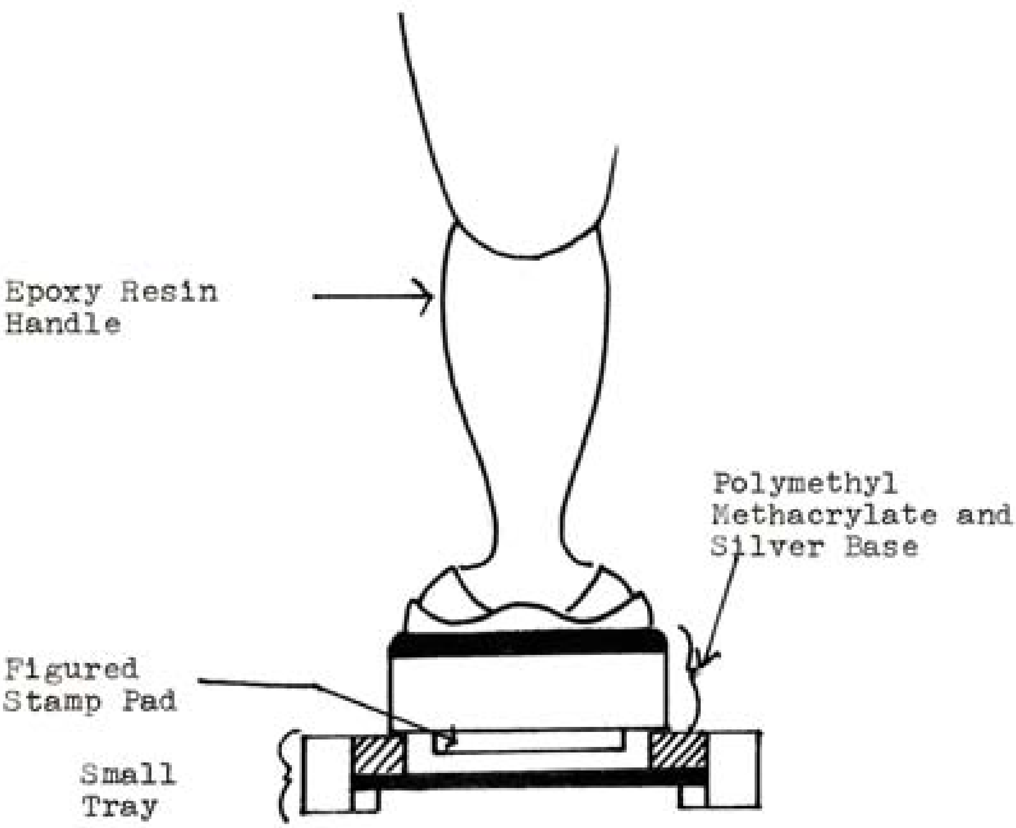


Fig. 17: Rubber Stamp Resting in Small Tray

Miscellaneous Information

Laminating Plastics

Various combinations of plastics and metals can be laminated together for a variety of effects. Different colors of the same plastic, different plastics, or plastic and metals can be chemically or mechanically bonded, then refined and buffed. When using a cement to bond two materials it is very important not to overheat when buffing so that the bond is not dissolved. When using a mechanical bond, such as a rivet, care must be taken not to crack the plastic. Also, since the area between the two materials is not sealed, it is easy to get buffing compound and dust in the joint. After joined, the materials can be filed, drilled, sawed and finished with interesting results.

Forging Polycarbonate

Polycarbonate can be "forged" with a hammer. By building up heat through successive blows, the plastic will move due to the heat and pressure being applied. Therefore, it is the speed with which you hammer and the amount of surface area struck which determines the amount moved. Polycarbonate was "forged" with a regular forging hammer on an anvil and reduced from 3/8 inch to 1/8 inch thickness before it cracked. It was then placed in boiling water, to test for memory. The piece maintained its deformation.

Polyformaldehyde, ('Delrin'), an Acetal Resin

An engineering plastic, 'Delrin' is tough and transluscent, with great rigidity and tensile strength. It is one of the most resilient plastics known, having good dimensional stability and the ability to retain its properties over a wide temperature range. An engineering plastic, it has been called "an admirable substitute for metals,"[16] and has found much popularity replacing metal parts in industry.

A laminated bracelet, handle for a letter opener, and blade for another letter opener were made of 'Delrin'. It machines readily with metal working tools without "drag", as evidenced in working with nylon. Having been taken to a 600 grit finish, it can be highly polished.

I attempted to sandblast 'Delrin', but this was unsuccessful in that the material retained some of the sand and looked very dirty afterwards.

When working with 'Delrin' sheet, the craftsman should be aware of the cure line that runs through the middle of the plate. Apparently when

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[16] E. G. Couzens and V. E. Yarsley, Plastics in the Modern World, p. 91.

'Delrin' is manufactured the outer layer solidifies first, pushing air bubbles and debris to the middle. If the sheet is to be carved and this layer is cut across at a wide angle, it will be difficult to clean and buff. It will always be noticeable, especially in a black piece. It was suggested that a thick piece of 'Delrin' be cut down the middle to remove the cure line, but such a cut will warp this plastic. If this is attempted, a guide should be consulted to anneal 'Delrin'. If done properly, a warp can be removed.

This material can be produced in colors, but for the most part is available only in white, natural (cream colored) and black.

Polyvinyl Chloride (P.V.C.)

P.V.C. is an interesting engineering plastic which is manufactured in a variety of grades. It is unable to sustain combustion, but decomposes when heated and is therefore limited to rigid forms. It can be highly plasticized and is difficult to cement, but can be readily welded.

Machining P.V.C. is a joy. Rather rubbery, it saws very well on a bandsaw using a 1/2 inch blade with 10 teeth per inch at a speed of 3000 FPM. Metal files work beautifully. The plastic tends to clog regular silicon carbide paper, but a paper called silicon carbide opencoat made for house painting and auto body work produced a good finish. The pin I made from P.V.C. was carved and taken to a 320 grit finish, then buffed with a plastic buffing coumpound and stitched cotton buff. Metal bobbing compound and tripoli were most unsatisfactory and impossible to remove. When buffed, P.V.C. has a beautiful cellular grain to it. One great advantage in using this plastic is that it is virtually acid resistant. Unfortunately the only colors available in the United States are a light and dark grey. However, colors are available in Europe.

CONCLUSION

Little information is available to the craftsman who wishes to work with plastics on a somewhat sophisticated level. For that person interested in the engineering plastics, the greatest source of informative material can be gathered from data published for industry. Through my involvement with plastics I have taken methods developed for industry and have altered them to an individual's manner of working. For the most part, plastics have been produced to serve as machine parts, structural elements, architectural addenda, etc. It is hoped that the pieces made for this thesis, however, show an entirely different aspect of these materials and will serve as a basis for further development of plastics combined with non-ferrous or, more specifically, precious metals.

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